

the whole of these instruments for me, and to whom I am indebted for some valuable suggestions; and finally to Mr. Landriset, of Geneva, my assistant since last January, whose care and perseverance, especially with reference to the determinations by Pettenkofer's method, have added not a little to the success of the inquiry.

The drawing of the instrument which accompanies this paper (Plate 2) needs no explanation beyond the few notes referring to letters at the foot of the plate.

“Researches in Stellar Photography. 1. In its relation to the Photometry of the Stars; 2. Its applicability to Astronomical Measurements of great Precision.” By C. PRITCHARD, Savilian Professor of Astronomy in Oxford. Received May 20. Read May 27, 1886.

Several attempts have already been made to connect the photographic images of stars with their photometric magnitudes, and consequently with their relative brightness; but hitherto, so far as I know, this relation has been sought by comparing the *impressions* made on the eye rather than as resulting from rigorous measures. With a view to the removal of this indefiniteness, unscientific unless it be unavoidable, I have undertaken a series of instrumental measures of the diameters of the photographic images impressed on sensitised films, which has led to the establishment of a remarkable physical relation (mathematically expressed) between the diameters of the stellar images and their photometric magnitudes, as determined by instrumental means: a method which seems to me to be free from systematic error and personal bias.

With this end chiefly in view, though accompanied also with the hope of obtaining still further, and perhaps even more valuable application of the photographic method to astronomical observations, I procured a number of gelatine dry plates, each being about 2 inches square. The comparative smallness of these plates was determined or suggested by my desire to obtain pictures of such small parts only of the sky as would fall within the ascertained limits of astronomical accuracy of the telescopic field of view, *i.e.*, a field possessing no measurable distortion; and consequently restricted to about a square degree. These plates were exposed in the focus of the well-known De La Rue reflecting telescope, of 13 inches aperture, erected in the University Observatory, at Oxford.

Several plates of the Pleiades were taken with varying times of exposure, and on these were impressed images of portions of the group, extending to stars of approximately the tenth magnitude. The

first use made of these photographic plates was to measure the diameter of those stars whose photometric magnitudes have already been ascertained by the Wedge photometer, and published in the "*Uranometria Nova Oxoniensis*," p. 94.

Before proceeding further, it is necessary to observe that the photographic images of the stars formed on the film possess in general a very sensible size, even when exposed for moderate intervals of time. It is not necessary here to enter upon the probable cause or causes of these considerable images, or of their peculiar nature; it is sufficient to indicate, as an example, that the image of Alcyone (mag. 3·12) on a plate exposed for (say) ten minutes, is a disk having a diameter of about 0·02 inch, equivalent to a diameter of 30'' in the focal plane of the telescope. As to the peculiar form of these images, it was long ago shown by Bond (in 1858)*, that when viewed under considerable magnifying power, they are not simply sharply defined circular disks, but are fringed all round with discrete black dots, separable under the higher powers of a microscope, and extending to some distance beyond the main black circular disk; nevertheless, when viewed in the comparatively low power of the double-image micrometer, or of the microscope attached to the macro-micrometer, actually used in the measurements, these discrete fringes are not salient, and do not interfere sensibly with the exactitude of the repeated measures.

As a matter of precaution, the diameters of the photographed images were measured, both by means of Airy's double-image micrometer (Greenwich observations), and by the De La Rue macro-micrometer described in vol. 47, "*Mem. Roy. Astron. Soc.*," and the trustworthiness of these measures was still further confirmed by observations made by means of a stage micrometer applied to an achromatic microscope of very considerable power. The results of these combined measures were then graphically plotted on paper prepared with ruled squares, the measured diameters being taken as the abscissæ, and the corresponding photometric magnitudes taken as ordinates. As usual, a curve was drawn by hand among the points plotted, and thus graphically connecting magnitudes in general with their corresponding diameters. A mere inspection at once suggested the mathematical connexion between these abscissæ and their ordinates, indicating a logarithmic curve, of which the equation would be—

$$y = A\epsilon^{-\frac{x}{a}},$$

where x is the measured diameter, and y is the corresponding magnitude of the star, here expressed on the scale that 2·05 shall represent the magnitude of Polaris, and 2·512 the light ratio in passing from one magnitude to the next. All this is in accordance with the ordi-

* "*Astr. Nachr.*," vol. 48 (1858), col. 1.

nary convention explained in "Mem. Roy. Astron. Soc.," vol. 47. But it should from the first be understood that any other convenient light ratio, and any other standard magnitude, might have been adopted. It may properly be here repeated that the object of the research is confined to the question whether a definite relation can be discovered between measured photographic images and the ordinary conventional magnitudes of stars.

If this equation expresses the true relation between diameter of image and magnitude, then an equation of condition for the determination of the numerical values of the constants becomes of the form—

$$\log y = \log \mu - \frac{x}{\delta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

the logarithms here being on the ordinary base 10; *i.e.*, if D, D' be the measured diameters of two stars *on the same plate*, and M, M' their corresponding magnitudes, then—

$$D - D' = \delta \log \frac{M'}{M} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

From this it follows that in the equation of condition (1), (derived from the original equation to the curve, *viz.*, $y = A\epsilon^{-\frac{x}{a}}$), the constant μ is the magnitude of the faintest star at all impressible on the plate for the exposure in question (or whose photographic diameter is zero), and δ denotes the diameter of that star whose magnitude is the tenth part of that of this zero star on that plate, this particular number (10) being necessarily introduced by the adoption of the Briggsean system of logarithms.

With regard to the relation (2)

$$D - D' = \delta \{\log M' - \log M\},$$

it is noticeable that it is in analogy with the fundamental relation existing between light and magnitude—

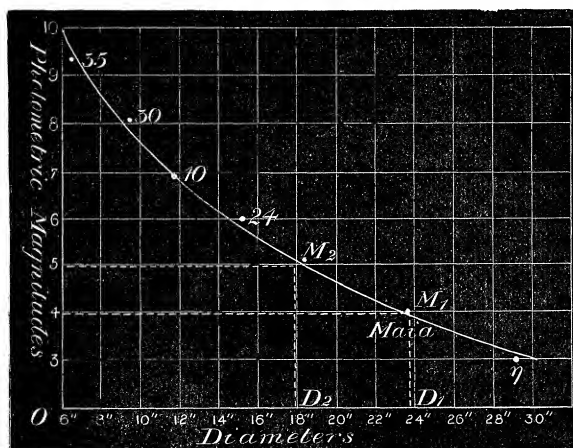
$$M - M' = K \{\log L' - \log L\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

We now proceed to the numerical computation of the constants (μ) and (δ), and consequently to the comparison of the resulting computed magnitudes with those instrumentally obtained by the Wedge Photometer.

The results of the present research are confined to the discussion of three plates of a portion of the Pleiades, exposed for 7, 12, and 15 minutes respectively on February 11 and April 2 of the present year, at the respective altitudes of $51^{\circ} 57'$, $23^{\circ} 49'$, and $21^{\circ} 50'$. The stars selected for measurement on these plates are twenty-four in

number, viz., those given in the following tables, and of which the magnitudes are given in the "Uranometria Nova Oxoniensis."

FIG. 1.



The curve having been formed as described, and practically represented above, then for each *integral* magnitude, such as D₁M₁, D₂M₂, the corresponding diameter OD₁ OD₂ was read off the curve itself, and the following equations of condition resulted.

$$\begin{aligned}
 \log 3 [0.47712] &= \mu - 30.00\delta \\
 \text{,, } 4 [0.60206] &= \mu - 23.49\delta \\
 \text{,, } 5 [0.69897] &= \mu - 18.69\delta \\
 \text{,, } 6 [0.77815] &= \mu - 14.88\delta \\
 \text{,, } 7 [0.84510] &= \mu - 11.58\delta \\
 \text{,, } 8 [0.90309] &= \mu - 9.00\delta \\
 \text{,, } 9 [0.95424] &= \mu - 7.38\delta
 \end{aligned}$$

A solution of these equations reduces the fundamental equation (1) to—

$$\log y = \log 12.82 - 0.02157x \quad . \quad . \quad . \quad . \quad (A)$$

The other two plates, similarly discussed, but each being absolutely independent in its results from the others, give—

$$\log y = \log 12.63 - 0.0216x \quad . \quad . \quad . \quad . \quad (B)$$

$$\text{,, } y = \log 11.69 - 0.0247x \quad . \quad . \quad . \quad . \quad (C)$$

From this investigation it may be gathered that the magnitude of the star which was commencing to form its photographic image on the

plate (A) after seven minutes' exposure, was 12·82 mag., and that the diameter of a star of the magnitude 1·28, would occupy on the plate in question a circular disk 46·36'' in diameter, or, linearly expressed, 0·024 inch.

Similarly for plates B and C, with the exception that the exposures and the altitudes of the stars are different, to say nothing of other possible differences, such as the chemical constitution of the films, the development of the images, and the meteorological circumstances attending the exposures. It is observable that in Plate B, although the exposure was twelve minutes instead of the seven for Plate A, nevertheless the zero star was *brighter* than for A, owing probably to the lower altitude or to the other causes mentioned above. For Plate C the exposure was still longer, viz., fifteen minutes, nevertheless, as the group was still lower in altitude, the zero star is the brightest of any of the three plates; the instructive character of these phenomena is obvious.

The results of applying the normal equations A, B, C severally to the twenty-four stars whose diameters were measured, are given in the subjoined Tables I, II, III, where, in the first column, is given the star's designation as originally applied by Bessel. In the second is given the measured diameter of its photographed image on the plate in question. This diameter expressed in seconds of arc corresponds to the angular magnitude under which that image would be seen when placed in the focus of the mirror (10 feet), and viewed from the centre of that mirror. In the third column of each table is given the photographic magnitude, computed from the normal equations A, B, C severally. Column 4 contains the photometric magnitude, as given in the "*Uranometria Nova Oxoniensis*," p. 94. The last column contains the difference between the two magnitudes.

Table I.—February 7th, 1886.

Plate A. Exposure 7 m. Altitude $51^{\circ} 57'$.

| Star's designation. | Measured diameter. | Computed (photographic) magnitude. | Photometric magnitude. | Difference C — O in mag. |
|---------------------------|-----------------------|--|---------------------------|--------------------------------|
| η Tauri..... | 29.16 | 3.01 | 3.12 | -0.11 |
| Maia..... | 23.21 | 4.05 | 3.96 | +0.09 |
| Atlas..... | 23.65 | 3.96 | 4.00 | -0.04 |
| Pleione..... | 19.41 | 4.89 | 5.46 | -0.57 |
| 24 <i>p</i> | 15.22 | 6.02 | 6.04 | -0.02 |
| 32..... | 13.19 | 6.66 | 6.34 | +0.32 |
| Asterope (<i>l</i>).... | 14.17 | 6.34 | 6.46 | -0.12 |
| 26 <i>s</i> | 13.34 | 6.61 | 6.56 | +0.05 |
| 24..... | 13.21 | 6.65 | 6.53 | +0.12 |
| 29..... | 12.80 | 6.79 | 6.58 | +0.21 |
| 12..... | 13.13 | 6.68 | 6.74 | -0.06 |
| 19..... | 12.24 | 6.98 | 6.78 | +0.20 |
| 22..... | 13.89 | 6.43 | 6.80 | -0.37 |
| 31..... | 11.34 | 7.30 | 6.81 | +0.49 |
| 10..... | 11.87 | 7.11 | 7.18 | -0.07 |
| 8..... | 10.74 | 7.52 | 7.36 | +0.16 |
| 20..... | 10.63 | 7.56 | 7.52 | +0.04 |
| 21..... | 9.82 | 7.87 | 7.60 | +0.27 |
| 18..... | 9.62 | 7.95 | 7.61 | +0.34 |
| 9..... | 9.93 | 7.83 | 7.68 | +0.15 |
| 30..... | 9.41 | 8.04 | 7.89 | +0.15 |
| 15..... | 8.49 | 8.41 | 8.09 | +0.32 |
| 13..... | 9.09 | 8.16 | 8.22 | -0.06 |
| 36..... | 7.90 | 8.66 | 9.07 | -0.41 |
| 35..... | 6.14 | 9.45 | 9.67 | -0.22 |

Table II.—April 2nd, 1886.

Plate B. Exposure 12 m. Altitude 21° 50'.

| Star's designation. | Measured diameter. | Computed (photographic) magnitude. | Photometric magnitude. | Difference C — O in mag. |
|------------------------|-----------------------|--|---------------------------|--------------------------------|
| η | 28.74 | 3.03 | 3.12 | —0.09 |
| Maia. | 23.47 | 3.93 | 3.96 | —0.03 |
| Atlas | 26.68 | 3.71 | 4.00 | —0.29 |
| Merope | 21.41 | 4.46 | 4.30 | +0.16 |
| Pleione | 19.70 | 4.75 | 5.46 | —0.71 |
| 24 p | 16.00 | 5.71 | 6.04 | —0.33 |
| 32. | 13.53 | 6.45 | 6.34 | +0.11 |
| 26 s | 13.80 | 6.37 | 6.56 | —0.19 |
| 24. | 13.84 | 6.36 | 6.53 | —0.17 |
| 29. | 12.70 | 6.72 | 6.58 | +0.14 |
| 12. | 12.29 | 6.86 | 6.74 | +0.12 |
| 19. | 12.67 | 6.73 | 6.78 | —0.05 |
| 22. | 13.55 | 6.44 | 6.80 | —0.36 |
| 31. | 11.60 | 7.10 | 6.81 | +0.29 |
| 17. | 12.28 | 6.86 | 6.84 | +0.02 |
| 33. | 12.55 | 6.77 | 6.78 | —0.01 |
| 10. | 11.26 | 7.22 | 7.18 | +0.04 |
| 8. | 10.79 | 7.39 | 7.36 | +0.03 |
| 20. | 10.46 | 7.51 | 7.52 | —0.01 |
| 18. | 10.00 | 7.69 | 7.61 | +0.08 |
| 7. | 10.53 | 7.49 | 7.54 | —0.05 |
| 9. | 9.90 | 7.73 | 7.68 | +0.05 |
| 30. | 9.76 | 7.78 | 7.89 | —0.11 |
| 15. | 8.56 | 8.26 | 8.09 | +0.17 |
| 13. | 9.14 | 8.02 | 8.22 | —0.20 |

Table III.—April 2nd, 1886.

Plate C. Exposure 15 m. Altitude $23^{\circ} 49'$.

| Star's designation. | Measured diameter. | Computed (photographic) magnitude. | Photometric magnitude. | Difference C — O in mag. |
|------------------------|-----------------------|--|---------------------------|--------------------------------|
| η | 23.04 | 3.16 | 3.12 | +0.04 |
| Maia..... | 17.85 | 4.33 | 3.96 | +0.37 |
| Atlas..... | 19.51 | 3.85 | 4.00 | -0.15 |
| Merope..... | 16.94 | 4.46 | 4.30 | +0.16 |
| Pleione..... | 16.36 | 4.61 | 5.46 | -0.85 |
| 24 p | 11.85 | 5.96 | 6.04 | -0.08 |
| 32..... | 10.54 | 6.42 | 6.34 | +0.08 |
| 26 s | 11.23 | 6.27 | 6.56 | -0.29 |
| 24..... | 10.25 | 6.53 | 6.53 | 0.00 |
| 29..... | 10.09 | 6.59 | 6.58 | +0.01 |
| 12..... | 10.23 | 6.55 | 6.74 | -0.19 |
| 19..... | 9.60 | 6.78 | 6.78 | 0.00 |
| 22..... | 10.40 | 6.47 | 6.80 | -0.33 |
| 31..... | 8.59 | 7.17 | 6.81 | +0.36 |
| 17..... | 8.66 | 7.14 | 6.84 | +0.30 |
| 33..... | 8.84 | 7.07 | 6.78 | +0.29 |
| 10..... | 7.69 | 7.55 | 7.18 | +0.37 |
| 8..... | 8.21 | 7.33 | 7.36 | -0.03 |
| 20..... | 8.18 | 7.35 | 7.52 | -0.17 |
| 18..... | 7.40 | 7.67 | 7.61 | +0.06 |
| 7..... | 8.03 | 7.40 | 7.54 | -0.14 |
| 9..... | 7.18 | 7.77 | 7.68 | +0.09 |
| 30..... | 6.29 | 8.17 | 7.89 | +0.28 |
| 15..... | 5.92 | 8.35 | 8.09 | +0.26 |
| 13..... | 6.49 | 8.08 | 8.22 | -0.14 |

A comparison of the numbers in the last column affords a definite indication that there does exist in nature a general definite relation between the photographic diameters and the intensities of the stellar lights impressed on the plate, and that this relation is truly represented by the equation—

$$D - D' = \delta \{ \log M' - \log M \}.$$

Nevertheless it is also made evident that although this relation is a fact for stars *on the average*, there are a few stars which stand out from that average, a result which might have been anticipated on account of the salient character of special spectra occasionally met with in certain stars. In the group examined above, the stars having this abnormal actinic action are Pleione, and Nos. 22 and 31. These stars give the same evidence of peculiarity in all the three plates; and from this circumstance it becomes clear that if a comparison is at any time to be made between the photographic and the photometric magnitudes, more than one plate should be taken, in order to be sure that any discordances are due to variations in the actual actinic action, and not to accidental circumstances. Omitting these three stars, the average deviation of the magnitude here computed photographically from that photometrically determined, is 0.16 mag. If these three stars be included it is 0.19 mag. Had it not been that the Pleiades group was rapidly approaching the sun at the time of these observations, the character of the spectra of the three exceptional stars would have been examined, with the view of explaining, if possible, their peculiar actinic action on the photographic film.

The general results of the foregoing research appears to be—

First. There does *in general* exist a remarkable and definite relation between the intensity of the actinism of a star on a photographic film, as expressed by the area of the image formed, and the intensity of the light as measured by a photometer. That relation also exhibits a certain analogy to the relation between the photometric magnitude and the actual intensity of the light of a star. These relations being expressed by the formula—

$$\frac{M}{M'} = K \log \frac{L'}{L}$$

$$\frac{D}{D'} = K' \log \frac{M'}{M}$$

where the relation is sufficiently evident.

Secondly. *Both* these relations are disturbed in the cases of any salient difference in the colours of particular stars, or at all events present analogous difficulties in dealing with them by way of definite measurement.

Thirdly. If it be established that the photographic film is permanent, we possess in the application of photography the certain and definite means of comparing at pleasure any changes which in the lapse of time (whether longer or shorter) may occur in the lustre of any star or group of stars, without the labour of continually measuring and recording the actual magnitude at any particular epoch. We possess, that is, a register, which can be examined when the emergency arising from any suspicious circumstance occurs.

II.—*On the Relation of the Dimensions of the Photographed Images of a Star to the Time of the Exposure of the Plate.*

It will be observed that so far as the foregoing investigations are concerned, the stars examined and compared are all on the same plate and exposed for the same time; and it is from such plates that the remarkable relation between the areas of the images and the photometric magnitude has been obtained. There is, however a still wider question than this, involving the alterations in the disk-areas caused by the variations of the time of exposure of any particular plate on which they are impressed. I do not propose to enter upon this question to the exhaustive extent which at the present day is required, by the extreme and hitherto unexpected duration of the times of exposure, extending now to hours rather than to minutes or seconds. I will here only explain that the question of the relation of time of exposure to the photographic diameter of a particular star impressed on a film was elaborately examined by Bond.* From exposures varying from one second to two minutes, he came to the conclusion that the area of a given star's photographic image impressed on a given plate varied directly as the time of exposure. The plates he used were the ordinary wet collodion plates of 1858. My own investigations, based on exposures even when limited to the same time as Bond's (but on the modern gelatine dry plates), led me to a very different conclusion, viz., that the area varies as the square root of the time of exposure.

Before, however, publishing the details of my observations, it is desirable to extend the time of exposure to far larger durations, and I abstain at present from further remarks thereon, with the exception that, judging from the remarkable photographs taken by the Brothers Henry at the Paris Observatory, Bond's conclusions appear to me (as at present advised, but subject to further examination) incompatible with observed fact. There are also some still more remarkable and interesting investigations relating indirectly to the same question, made recently at Potsdam by Dr. Lohse ("Astr. Nachr.," vol. 111 (1885), col. 147), which may require remark, and I hope at an early

* "Astr. Nachr.," vol. 49 (1858), col. 81.

opportunity to make the whole subject the basis of a further communication. I will, however, add here that I have found the fringes of discrete dots which surround the images on the original negative entirely disappear on transferring them to a positive print, and leave their positive images simply as clean cut disks, whose diameters are sensibly the same as the measured diameters of the concrete disks on the original negative. It is conceivable that in printing, the light penetrates through the interstices of the fringe.

III.—*Applicability of Photography to Astronomical Measurements of Great Precision.*

The scientific interest and importance attached to the possession of a register of the relative lustre of the stars, virtually exhibited on a permanent photographic film, capable of re-examination at any time, and accessible at will, are, if possible, surpassed by the value attachable to the measurability of their relative positions, provided only the accuracy of the measures made upon the film is equal to that obtainable by the application of the best astronomical instruments to the sky itself. Three questions, in fact, here present themselves in relation to this matter. The first is, whether the photographic pictures accurately represent a portion of the skies; the second is, whether the relative co-ordinates of the star images are measurable with as much delicacy and certainty as they are by the heliometer, or any other form of micrometer, applied to the sky itself: and the third question has reference to the permanence of the photographic film.

For present convenience, I shall consider the reply to the first two of these questions as involved in the same evidence. In order to settle these points, several photographic plates of stars situated in portions of the Pleiades group, already referred to, were selected for examination. On each of these the image of η Tauri (Alcyone) is impressed, together with that of many other stars in the group, and specially for this purpose twenty-five of the stars, whose distances from Alcyone had been so carefully measured by Bessel with his famous heliometer in 1838—1842. These distances from Alcyone on the several films were each measured, and as far as possible with as many repetitions as those adopted by Bessel himself. Inasmuch as the plates were taken at different altitudes on different nights, the necessity arose for applying small numerical corrections for the varying effects of refraction, and where necessary, other small corrections for aberration were applied, in order that the resulting distances might be strictly comparable *inter se*. This examination of the amount of correspondence in the measures is the only object here, for the moment, entertained.

As far as the general mass, or great majority, of these observations is concerned, it is not necessary to give all the particulars, but I have selected the first sets of measures as affording an average specimen of the whole work. These results are exhibited in Table IV; and in Table V are given the mean deviations of the whole twenty-five stars, deduced as in the case of the six for which the complete details are printed in Table IV.

Table IV.—Comparison of Relative Accordances of the Photographic Measures of Distances of Stars from Alcyone *inter se*, with similar measures made by Bessel.

| Number of plate. | Distance measured | | Deviation from the mean | |
|------------------|------------------------|------------------------|-------------------------|---------------------|
| | On photograph. | With heliometer. | On photograph. | In heliometer. |
| Star 7. | | | | |
| Plate I..... | 1355 ^{''} ·65 | 1355 ^{''} ·02 | 0 ^{''} ·27 | 0 ^{''} ·04 |
| „ II..... | 1355 ^{''} ·11 | 1355 ^{''} ·39 | 0 ^{''} ·27 | 0 ^{''} ·41 |
| „ III..... | 1355 ^{''} ·43 | 1354 ^{''} ·74 | 0 ^{''} ·05 | 0 ^{''} ·24 |
| „ IV..... | 1355 ^{''} ·32 | 1354 ^{''} ·76 | 0 ^{''} ·06 | 0 ^{''} ·22 |
| Mean | 1355 ^{''} ·38 | 1354 ^{''} ·98 | 0 ^{''} ·16 | 0 ^{''} ·23 |
| Star 8. | | | | |
| Plate I..... | 1081 ^{''} ·39 | 1080 ^{''} ·27 | 0 ^{''} ·51 | 0 ^{''} ·12 |
| „ II..... | 1080 ^{''} ·68 | 1080 ^{''} ·48 | 0 ^{''} ·20 | 0 ^{''} ·33 |
| „ III..... | 1080 ^{''} ·79 | 1080 ^{''} ·40 | 0 ^{''} ·09 | 0 ^{''} ·25 |
| „ IV..... | 1080 ^{''} ·85 | 1080 ^{''} ·25 | 0 ^{''} ·03 | 0 ^{''} ·10 |
| „ V..... | 1081 ^{''} ·04 | 1079 ^{''} ·62 | 0 ^{''} ·16 | 0 ^{''} ·53 |
| „ VI..... | 1080 ^{''} ·52 | 1079 ^{''} ·85 | 0 ^{''} ·36 | 0 ^{''} ·30 |
| Mean | 1080 ^{''} ·88 | 1080 ^{''} ·15 | 0 ^{''} ·22 | 0 ^{''} ·27 |
| Star 9. | | | | |
| Plate I..... | 1045 ^{''} ·12 | 1045 ^{''} ·07 | 0 ^{''} ·00 | 0 ^{''} ·22 |
| „ II..... | 1045 ^{''} ·21 | 1045 ^{''} ·06 | 0 ^{''} ·09 | 0 ^{''} ·21 |
| „ III..... | 1045 ^{''} ·00 | 1044 ^{''} ·88 | 0 ^{''} ·12 | 0 ^{''} ·03 |
| „ IV..... | 1045 ^{''} ·13 | 1044 ^{''} ·39 | 0 ^{''} ·01 | 0 ^{''} ·46 |
| Mean | 1045 ^{''} ·12 | 1044 ^{''} ·85 | 0 ^{''} ·05 | 0 ^{''} ·23 |

Table IV—*continued*.

| Number of plate. | Distance measured. | | Deviation from the mean. | |
|------------------|------------------------|------------------------|--------------------------|---------------------|
| | On photograph. | With heliometer. | On photograph. | In heliometer. |
| Star 10. | | | | |
| Plate I..... | 1003 ^{''} ·35 | 1002 ^{''} ·63 | 0 ^{''} ·47 | 0 ^{''} ·13 |
| „ II..... | 1003·00 | 1002·57 | 0·12 | 0·07 |
| „ III..... | 1002·11 | 1002·49 | 0·77 | 0·01 |
| „ IV..... | 1003·06 | 1002·29 | 0·18 | 0·21 |
| Mean | 1002·88 | 1002·50 | 0·38 | 0·11 |
| Star 12. | | | | |
| Plate I..... | 1548 ^{''} ·58 | 1547 ^{''} ·27 | 0 ^{''} ·65 | 0 ^{''} ·29 |
| „ II..... | 1547·94 | 1547·47 | 0·01 | 0·09 |
| „ III..... | 1547·98 | 1547·86 | 0·05 | 0·30 |
| „ IV..... | 1547·21 | 1547·65 | 0·72 | 0·09 |
| Mean | 1547·93 | 1547·56 | 0·36 | 0·19 |
| Star 13. | | | | |
| Plate I..... | 521 ^{''} ·99 | 521 ^{''} ·61 | 0 ^{''} ·14 | 0 ^{''} ·23 |
| „ II..... | 522·21 | 521·52 | 0·08 | 0·14 |
| „ III..... | 522·15 | 521·20 | 0·02 | 0·18 |
| „ IV..... | 522·15 | 521·17 | 0·02 | 0·21 |
| Mean | 522·13 | 521·38 | 0·06 | 0·19 |

Table V.

| Star. | Mean deviation | | Star. | Mean deviation | |
|---------------------------|--------------------|--------------------|------------------|--------------------|--------------------|
| | On photograph. | In heliometer. | | On photograph. | In heliometer. |
| No. 7 | 0 ^{''} 16 | 0 ^{''} 23 | No. 24 | 0 ^{''} 27 | 0 ^{''} 20 |
| „ 8 | 0 ^{''} 22 | 0 ^{''} 27 | „ 27 | 0 ^{''} 18 | 0 ^{''} 11 |
| „ 9 | 0 ^{''} 05 | 0 ^{''} 23 | „ 29 | 0 ^{''} 03 | 0 ^{''} 25 |
| „ 10 | 0 ^{''} 38 | 0 ^{''} 11 | „ 30 | 0 ^{''} 32 | 0 ^{''} 47 |
| „ 12 | 0 ^{''} 36 | 0 ^{''} 19 | „ 31 | 0 ^{''} 48 | 0 ^{''} 36 |
| „ 13 | 0 ^{''} 05 | 0 ^{''} 19 | „ 32 | 0 ^{''} 17 | 0 ^{''} 37 |
| „ 15 | 0 ^{''} 31 | 0 ^{''} 20 | „ 33 | 0 ^{''} 45 | 0 ^{''} 42 |
| „ 24 ^p | 0 ^{''} 23 | 0 ^{''} 26 | | | |
| „ 17 | 0 ^{''} 23 | 0 ^{''} 33 | Merope | 0 ^{''} 24 | * |
| „ 18 | 0 ^{''} 12 | 0 ^{''} 18 | Maia | 0 ^{''} 31 | * |
| „ 19 | 0 ^{''} 09 | 0 ^{''} 71 | Atlas | 0 ^{''} 13 | * |
| „ 20 | 0 ^{''} 39 | 0 ^{''} 43 | Pleione | 0 ^{''} 28 | * |
| „ 22 | 0 ^{''} 37 | 0 ^{''} 43 | 26s | 0 ^{''} 24 | * |

* For these five stars, Bessel has not expressed the individual results in seconds of arc.

The average discordance for the entire group is in the case of photographic measures 0^{''}24^{''}, and in the case of heliometer measures 0^{''}29^{''}.

In the above preceding clause I have adopted the term *general mass*, because on one of the plates (fig. 2) there occurs a somewhat curious and instructive fact, viz., that while for nineteen instances of stars measured from η Tauri, the distances agree with those of the same stars on the other three plates, there is a sensible discordance between the measures of Atlas, Pleione, Nos. 29, 31, 32, and 33, when compared with the similar measures on the three other plates. This fact indicates a distortion of the film at the places where these six stars are impressed. On inspecting the diagram of the plate, it is observable that all these six stars, exhibiting these discordances of distance from η , lie on the same portion of the plate. It follows, necessarily, that three of the plates must accurately represent the portion of the heavens impressed, and the fourth plate in those portions only which exhibit an identity with the other three. From this fact we conclude that it is not safe to regard any single plate as necessarily accurate in itself, unless it is corroborated by the identity of exact measurements, when compared with others also. The discordances here referred to are small, but existent, perceptible, and in themselves destructive of accurate astronomical conclusions involved therein.

FIG. 2.

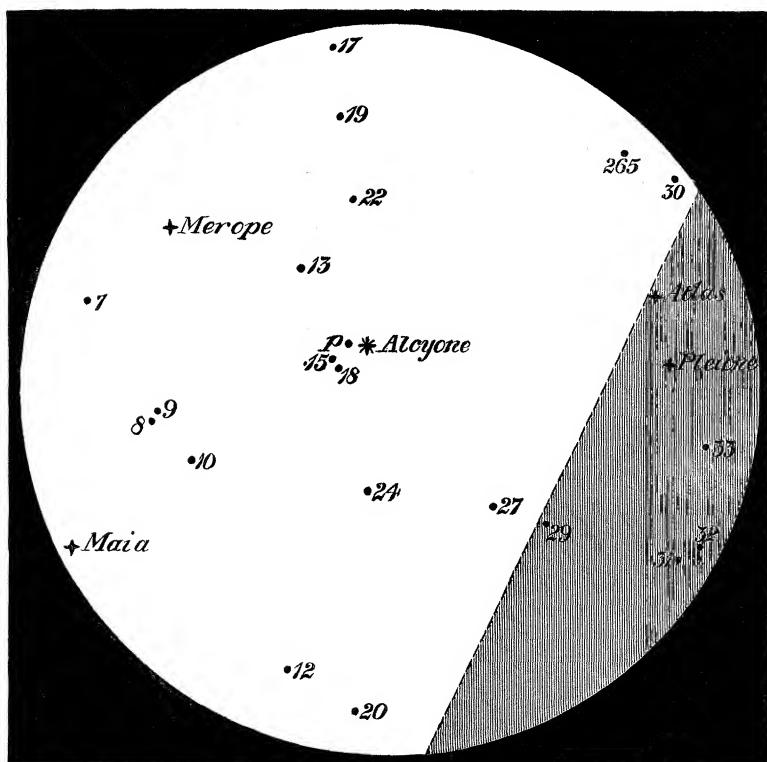


Diagram of stars in the Pleiades, as seen in an inverting telescope. The portion of the film distorted is shown by the shaded portion.

I now proceed to give the details of the individual measures of the six stars which present the anomaly in question, and contiguous to them will be found the accordances of the similar measures on the three other plates.

Table VI.—Discordant Measures of the Six Stars on the Disturbed Film. Plate IV.

| Number of plate. | Atlas. | Pleione. | Star 29. |
|---------------------|------------------------|------------------------|------------------------|
| Plate I..... | 1391 ^{''} ·14 | 1402 ^{''} ·67 | 1202 ^{''} ·23 |
| „ II..... | 1391·46 | 1403·50 | 1202·29 |
| „ III..... | 1391·42 | 1403·08 | 1202·31 |
| Mean | 1391·34 | 1403·08 | 1202·28 |
| „ IV discordant ... | 1391·77 | 1403·95 | 1203·04 |
| Number of plate. | Star 31. | Star 32. | Star 33. |
| Plate I..... | 1806 ^{''} ·11 | 1832 ^{''} ·58 | 1678 ^{''} ·39 |
| „ II..... | 1807·39 | 1832·89 | 1679·56 |
| „ III..... | 1806·99 | 1833·02 | 1679·24 |
| Mean | 1806·83 | 1832·83 | 1679·06 |
| „ IV discordant ... | 1808·55 | 1834·15 | 1680·34 |

It may be noticed that the discordances for Atlas and 29 are not so conspicuous as for the remaining stars, indicating that the principal disturbance of the film has taken place in the neighbourhood of 31, 32, and 33. The maximum discordance applies to the Star 31, where it is 1·7''; and the least disturbances applies to *Atlas*, where it does not reach half a second of arc.

The accordance of the measures given in Tables IV and V *inter se*, is quite equal to that exhibited by the measures of the illustrious astronomer of Königsberg. I confess that, having already had a long experience of the results of repeated measures of distances of spots on the moon as obtained from lunar photographs ("Mem. Roy. Astron. Soc.," vol. 47 (1883)), and being at the same time aware also of Dr. De La Rue's great success in measuring solar photographic images, I was not altogether surprised, but agreeably satisfied by the removal of all doubt and uncertainty. But, in reference to this question, we must not overlook the fact of the generic distinction which exists between the circumstances attending the production of these solar and lunar photographs and these stellar images formed on photographic films of a totally different description, and which latter films do necessarily present difficulties and suspicions not applicable to the former. In the former case the collodion plates were exposed for at most a very few seconds, or even for fractions of a second; but in the case of the star plates, the exposures last, not only through very many minutes, but the several star images make their appearance, according to their

relative brightness, only after varying times of exposure. It would therefore have been premature, or even unscientific, to argue *à priori* of the reliability of the latter measures from those of the former.

From inspection of Table V it will be found that the general error of the whole group of measures of the photographic plates, regarded as measures of the same quantity, is $0.24''$, and of the heliometer $0.29''$. Even this minute error would probably have been smaller had it not been for a practical difficulty, which arises in the accurate bisection of the disks of the star images. This difficulty, though it exists also to a proportionate extent in the use of any filar micrometer applied to the brighter stars in the skies, does not exist to an equal degree in the case of heliometer measures. Nevertheless, such is the convenience of leisurely bisecting even the comparatively large photographic disk on a steady film, that the final results of the photographic measures are, on the whole, slightly more accordant than those secured by the use of the heliometer. In point of facility and rapidity, the advantages of the photographic method are enormous.

Having mentioned the error necessarily connected with bisection of the star disk, it is desirable to present a specimen of what actually occurs. Accordingly I give a short table, containing the detail of the errors made in continually bisecting two star disks, such as actually occurred in reference to Maia and Asterope, of diameters $25''$ and $15''$ respectively.

Table VII.

| Maia, mag. 4.00. | | Asterope, mag. 5.98. | |
|---|--|---|--|
| Reading of screw at apparent bisection. | Difference of readings from mean in seconds of arc. | Reading of screw at apparent bisection. | Difference of readings from mean in seconds of arc. |
| in. | | in. | |
| 0.90822 | $0.17''$ | 0.90774 | $0.25''$ |
| 0.90811 | 0.36 | 0.90772 | 0.28 |
| 0.90826 | 0.10 | 0.90793 | 0.09 |
| 0.90841 | 0.15 | 0.90799 | 0.19 |
| 0.90859 | 0.46 | 0.90785 | 0.05 |
| 0.90861 | 0.50 | 0.90788 | 0.00 |
| 0.90870 | 0.65 | 0.90803 | 0.26 |
| 0.90846 | 0.24 | 0.90791 | 0.05 |
| 0.90827 | 0.09 | 0.90788 | 0.00 |
| 0.90810 | 0.38 | 0.90781 | 0.12 |
| 0.90816 | 0.27 | 0.90779 | 0.16 |
| 0.90811 | 0.36 | 0.90799 | 0.19 |
| 0.90816 | 0.27 | | |
| Mean 0.90832 | 0.31 | 0.90788 | 0.14 |

Comparing this liability of error in the bisection of each star, in obtaining its distance from η , with the whole liability to error in distance, which is $0.24''$, it follows that probably the whole error in the distance measures arises from the bisection, and that therefore the film has remained undisturbed in the direction of distance. Another practically important conclusion is that the exposure of the plates should not continue beyond the time necessary to form distinct disks of the stars to be measured, inasmuch as an increased enlargement of the photographic image necessarily entails an increased error in its bisection (see Table V). Hence, if the stars to be measured differ very greatly in magnitude, then it may be desirable to connect the brightest stars with the fainter by means of stars of intermediate magnitude.

Such, then, appears to be the comparatively rigorous character of photographic measurement: but I hope to carry the investigation still further, by the application thereof to the determination of stellar parallax, for which the method appears to be eminently adapted.

Another investigation presents itself in the inquiry as to the effect of atmospheric absorption at varying altitudes on the image impressed.

With regard to the question of the permanence of the film, it would at present be premature to speak: it might be unsafe to argue from the known permanence of the collodion plates on which the lunar images are impressed, but so far as the present knowledge suggests there is no evidence of deterioration. I propose, however, to measure a few distances periodically, as well as the diameters of the larger star disks.

“Contribution to the Study of Intestinal Rest and Movement.”

By J. THEODORE CASH, M.D. Communicated by T. LAUDER BRUNTON, M.D., F.R.S., &c. Received May 25. Read May 27, 1886.

During the last two years, as opportunity has permitted, I have been engaged in an experimental study of the various factors which contribute to movement or rest of the small intestine.

This research has furnished me with much information of an analytical character, but it seemed desirable to supplement and, in some degree, to control this, by investigating the general conditions which influence such changes in a healthy animal in which all the functions exerting an influence upon the viscera are in full operation. The most promising means for effecting this purpose appeared to be the establishing of a Vella's fistula which would permit of thorough

FIG. 1.

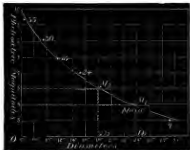


Figure 1

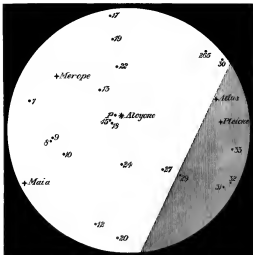


Diagram of stars in the Pleiades, as seen in an inverting telescope. The portion of the film distorted is shown by the shaded portion.